Understanding Predictability of the Ocean

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LONG-TERM GOALS

The long-term scientific goals of this research project are:

1. To develop an understanding of how some sources of error affect ocean predictability.
2. To further develop the state-of-the-art ROMS 4D-Var by extending the observational types and applications.
3. To gain experience and develop ideas for the limitations to the predictability of oceanic processes.
4. To train a new generation of students in data assimilation and ROMS.
5. As a YIP award, to strengthen the early career and build the research path for myself as young faculty.

OBJECTIVES

The primary objectives of this project are: (i) to assess how particular observations may affect predictability; (ii) to assess how particular model parameterizations can affect predictability; and (iii) to compare these results with full ocean-state estimates generated from the ΨEX acoustic experiment.

APPROACH

To improve forecasts of the ocean circulation, we must understand how both observations and model error impact the predictability. Forecasts are limited by the growth of uncertainty, and the aim is to quantify the uncertainty in forecasting regional oceans to prior choices in the assimilated observations and model parameters. In previous work (Powell and Moore, 2009; Powell et al., 2009), we found that particular satellite observations are more significant to the forecast skill than others. During the initial period, the forecast depends only upon the initial conditions; however, as the forecast length growths, model error — as represented by uncertainty in the model parameters — dominates the forecast skill.

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The ocean model used in this research is the ONR-funded Regional Ocean Modeling System (ROMS): a free-surface, hydrostatic, primitive equation ocean model discretized with a terrain following vertical coordinate system (Shchepetkin and McWilliams, 2005). The model has multiple sub-gridscale parameterizations of vertical mixing along with many options for open boundary conditions. Time-splitting of barotropic and baroclinic motions enables efficient time integration. ROMS has been successfully used to model many regions of the world ocean (see `http://www.myroms.org/papers`) and is a widely used community resource.

To understand the importance of observations, we will implement an adjoint of the observation-space assimilation procedure (Chua and Bennett, 2001; Di Lorenzo et al., 2007) for the Hawaiian regional model (Natarov and Powell, 2009) to quantify the sensitivity of the forecast to satellite, HF radar, autonomous gliders, and long-term fixed mooring data. In anticipation of the Philippine experiment, we will develop the scheme to assimilate acoustic travel time data from the historical HOME project.

A great deal of effort has gone into the adjoint and tangent-linear models of ROMS (Moore et al., 2004) along with the assimilation methods (Di Lorenzo et al., 2007; Powell et al., 2008) that have spawned several successful studies (e.g., Powell and Moore, 2009; Muccino et al., 2008; Powell et al., 2009; Broquet et al., 2009). In previous ONR-funded work, we developed the framework for estimating the analysis error (Powell and Moore, 2009) from the observations and a ROMS prediction system, which combines multi-resolution assimilation and ensemble prediction for an operational NWP-type system (Powell et al., 2009). These previous works are the foundational toolkit for this work.

Model error is comprised of a number of independent factors and each source should be addressed separately. For this study, we assume the model error is dominated by uncertainties in the physical parameterizations in the model. For example, incorrect viscosity values may create excessive mixing that cascades throughout the circulation estimate. By assigning uncertainty to the model parameters, they can be examined like dynamic variables.

ROMS currently contains over 70 adjustable parameters that affect the physics of the time integration. For this experiment, we propose to quantify the model error from the three sets of parameters that dominate the numerical solution: the nonlinear equation of state, horizontal mixing and diffusion, and the vertical mixing parameters. In ROMS, the equation of state and horizontal mixing are controlled by user-specified runtime variables (total of 8) that are well-suited for this study. The vertical mixing parameters depend upon the compile-time choice of procedure, so we will focus only on the 3 buoyancy parameters of the ROMS generic length-scale mixing scheme (Warner et al., 2005).

To verify the methods developed, a well-observed ocean state is required. The timing of this work coincides with the Ocean Acoustics Deep Water experiment in the Philippine Sea: a large-scale acoustic tomography and glider field experiment beginning April, 2010. Collaboration with this experiment presents a unique opportunity to estimate and quantify the predictive uncertainty of the model versus the "truth."

WORK COMPLETED

During the current reporting period, we have been funded for a total of 3 months. During this time, we have completed the following tasks:

1. Began collaborations with the ΨEX team.

2. Attended the NPAL meeting in Monterey, CA to participate in the planning and discussion of the ΨEX cruise and deployment schedule.
3. Hired two graduate students: one pursuing a Ph.D. in physical oceanography and a second pursuing a M.S. in physical oceanography.
4. Began collaborative work with Bruce Cornuelle to coordinate our efforts to enable assimilation of tomographic travel times. He is working to add assimilation into the MITgcm, while I am working with ROMS.

RESULTS

As this project was just funded, I do not have any new results to announce. Preliminary experiments in the Hawaiian region are now under way to quantify the impact of a variety of observations on the predictive skill of the local model. We are also conducting early thought experiments on the feasibility of using the adjoint model for parameter estimation (as opposed to Markovian techniques). Our planning for the NPAL experiments is complete, and we are currently developing a regional ROMS model for the Philippines Sea.

IMPACT/APPLICATIONS

As numerical models are becoming more widely accepted in oceanographic applications, a quantified estimate of the uncertainties must accompany any forecast to aid in the understanding of the generated fields. This project will contribute to the ROMS community by both developing and utilizing methods that will be made available for estimating the errors from parameters as well as estimates of the observations that most improve regional models. The foundation for this work is present only in ROMS as it is the only model that possesses such a wide range of 4D-Var algorithms. This project will contribute to further enhancement and development of these tools and algorithms.

TRANSITIONS

The new methods for assimilating tomography and assessing sensitivity to parameters that are developed as part of this project will be made available to the ROMS community and will hopefully be actively used and further developed by other research groups in the U.S. and elsewhere as user competence increases. The ROMS International Workshop will be hosted by the PI in April, 2010 at the University of Hawaii and will have training sessions to introduce basic concepts.

RELATED PROJECTS

This project is collaborating with the following ONR supported projects:

- "A community Terrain-Following Ocean Model (ROMS)", PI Hernan Arango, grant number N00014-08-1-0542.
- "North Pacific Acoustic Laboratory: Deep Water Acoustic Propagation in the Philippine Sea," PI Peter Worcester, ONR Grant N00014-08-1-0840.

- “The ROMS IAS Data Assimilation and Prediction System: Quantifying Uncertainty”, PI Andrew Moore, grant number N00014-08-1-0556.

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